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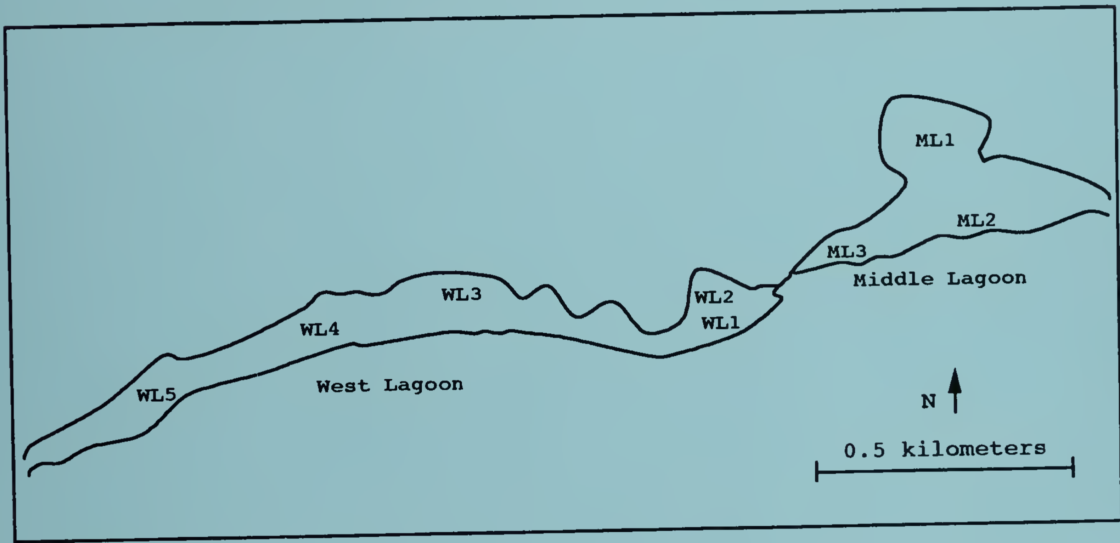

A Research Report to the Challenge Grant Cost Share Program, Water Resources Division, National Park Service, Fort Collins, Colorado, and the Indiana Dunes National Lakeshore, Porter, Indiana

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I. Executive Summary

The Grand Calumet River, near Gary Indiana, is within one of the Great Lakes Areas of Concern. It has been identified as having severe environmental contamination with impairment of all 14 designated uses (Hartig and Zarull 1992). The Grand Calumet Lagoons, on the western edge of the Indiana Dunes National Lakeshore (INDU), are partially bounded (West Lagoon) by steel plant property that may impact the biota of the lagoons. The objective of this study was to assess the toxicity of sediments of the Grand Calumet Lagoons to aquatic organisms using standard aquatic toxicity bioassays.

Study Site

Sediment samples were collected within INDU boundaries from two sites in the Middle Lagoon (ML1, ML2) and from two sites in the West Lagoon (WL1, WL2). Collection sites WL3, WL4, and WL5 in the western half of the West Lagoon are within the property boundaries of a steel plant that borders the INDU. Sediments were analyzed for heavy metal and organic pollutants and assayed for toxicity using aquatic organisms.

Contaminants in Sediments

The average increase in concentration of metals and other contaminants in sediments from the eastern portion of the West Lagoon (WL1-WL3) was 2.5 times that of reference sites in the Middle Lagoon (ML1-ML3). The average increase in concentrations of metals in sediments from the western reach of the West Lagoon (WL4 and WL5) was 8 to 9 times that of ML1-ML3. Additionally, sediments from WL4 may be contaminated with low levels of polycyclic aromatic hydrocarbons (PAHs). Sediments from the extreme western edge

of the West Lagoon (WL5) were heavily contaminated with PAHs. When compared to other polluted rivers in the U.S., sediments of the western edge of the West Lagoon were mildly contaminated with heavy metals, but highly contaminated with PAHs.

Toxicity of Sediments

Bioassays with sediments from WL1-WL4 produced slight evidence of toxicity in aquatic organisms. When compared to other studies, the concentrations of metals in sediments at sites WL1-WL4 were below that found to cause low-level effects in aquatic organisms (Long and Morgan 1990). The concentrations of PAHs at WL4 were not high enough to contribute to toxicity. Evidence from literature and results from our data suggested that sediments from sites WL1-WL4 were slightly toxic to aquatic organisms. Since individual metal concentrations in these sediments were below that considered toxic, the source of toxicity in sediments from WL1-WL4 could be due to synergistic effects or due to some unknown source of toxicity.

The sediments from WL5 were extremely toxic to *Pimephales*. All minnow larvae died within hours of exposure to whole sediments from WL5. Although sediments from WL5 had elevated concentrations of metals, the concentrations of PAHs were more than an order of magnitude greater than those necessary to cause major biological effects in aquatic organisms. Despite the tight binding of PAHs to organic particles in sediments (McGroddy, et al. 1996), the concentrations of these compounds in whole sediments from WL5 would presumably produce concentrations of PAHs in interstitial water that would exceed the 10-day LC50 for sediment-inhabiting *Hyalella*.

The concentrations of PAH compounds in whole sediments from WL5 exceeded the mean sediment quality criteria proposed by the U.S. Environmental Protection Agency (Pastorok, et al.

1994). Additionally, data from our study suggested that the sediments of WL5 were acutely toxic to aquatic organisms. Thus, it is very likely that toxic sediments in the western portion of the West Lagoon have caused significant negative effects to aquatic organisms.

General Comments

In order to properly manage contaminated sediments, managers need to know the concentration of contaminants in sediments, the toxicity of contaminated sediments, and to understand the dynamics of contaminant fate and effects in the aquatic system (Burton and MacPherson 1995; Reynoldson and Day 1993). Additionally, because of the extent of contamination and eventual application of sediment quality criteria, remediation of sediments in the lagoons near INDU is very probable. Before remediation is considered, resource managers need to understand the risks associated with contaminated sediments in the West Lagoon.

II. Management Options and Information Needs

Significant negative impacts have occurred in the West Lagoon of the Grand Calumet Lagoon System. We recommend that the following actions be taken to determine the significance and extent of impacts and to best determine remediation strategies for toxic sediments in the West Lagoon.

1. Ecosystem studies should assess the extent of the effects of PAH contamination in the West Lagoon. This should include assessments of several levels of trophic structure (e.g. algae-invertebrates- macrophytes-fish-birds-mammals).

2. The extent of PAH contamination should be determined both spatially (hectares) and by depth. The total

volume of highly contaminated sediments will help determine the scope of contamination. Chemical analyses and toxicity assays should be used to survey the sediments in the lagoons to quantify the extent of contamination and to determine priority areas for remediation.

3. The sources of PAH and metal contamination should be identified and terminated. Slag piles, coke piles and a hazardous waste dump are highly suspected sources of contamination in the West Lagoon. The routes of contamination (groundwater, surface water, atmospheric deposition) should also be identified.

4. A biological monitoring program should be implemented so that baseline variables can be recorded and compared with those during and after remediation efforts. Biological indicators of exposure and effects could be effective at determining a biologically-relevant no-effects concentration of contamination.

Remediation of PAH-contaminated sediments can lessen the toxicity of these contaminants to aquatic organisms in a reasonable period of time. Baumann and Harshbarger (1995) reported that the concentration of PAHs in sediments of the Black River decreased significantly and were associated with significant decreases in the incidences of tumors in fishes four years after the source of PAH contamination was terminated. However, we recommend that studies be implemented to determine the best strategies for remediation of toxic sediments in the West Lagoon. Currently, plans are underway to remediate sediments in the eastern five miles of the Grand Calumet River. It is likely that sediments in the West Lagoon will also be proposed for dredging. It is necessary for the management of contaminated sediments to

include studies that will help predict the consequences and measure the effectiveness of remediation. Therefore, experiments could be designed in the West Lagoon that could help predict the effects of, and the effectiveness of sediment remediation in the Grand Calumet River and in the lagoons. However, unless the sources of contamination have been terminated, then remediation may be premature.

III. Background

Contaminants sorbed to aquatic sediments are a significant source of contamination in aquatic ecosystems. Due to historic inputs, many polluted rivers and estuaries have sediments with heavy metals and organic pollutants orders of magnitude greater than those in the water column (Barron 1995). Although sediments act as a sink (temporary storage) for contaminants, they may also provide a persistent source of toxic exposure to aquatic organisms (Burton and MacPherson 1995).

Although discharges of toxic substances have been reduced in the last 20 years, several major river systems in the Great Lakes area of the United States have sediments with significant levels of toxic contaminants. Of the 42 locations in the Great Lakes region designated as Areas of Concern (AOC), 41 sites are considered to have sediments with major contamination problems (International Joint Commission 1987; Hartig and Zarull 1991). Of the 31 AOCs in the United States, all completed Remedial Action Plans have identified contaminated sediments as a significant problem (U.S. Environmental Protection Agency 1996a). At most of these locations, advisories against fish consumption are in place (U.S. Environmental Protection Agency 1996a).

Waterways in which sediment contamination is a problem are being considered for site remediation (Reynoldson and Day 1993; U.S. Environmental Protection Agency 1996b). However, before developing specific plans to remediate contaminated

sediments, it is necessary to characterize the nature and extent of sediment contamination. Most AOCs had limited access to sediment information to assist them in addressing characterization and remediation questions (U.S. Environmental Protection Agency 1996a). In order to properly manage contaminated sediments, managers need to know the concentration of contaminants in sediments, the toxicity of contaminated sediments, and to understand the dynamics of contaminant fate and effects in the river system (Burton and MacPherson 1995; Reynoldson and Day 1993).

The Grand Calumet River, near Gary Indiana, is within one of the Great Lakes Areas of Concern. It has been identified as having severe environmental contamination with impairment of all 14 designated uses (Hartig and Zarull 1992). The fish community of the Grand Calumet River comprises only 10 species, is dominated by cyprinids (90%), and produces very poor scores of the Index of Biotic Integrity (Sobeich et al. 1994; Stewart and Butcher 1997; Simon and Stewart, in press). Fish-consumption advisories have been posted for select species with consumption categories ranging from unlimited consumption to "do not eat", depending on the size and species (Indiana State Department of Health 1997). The Grand Calumet Lagoons on the western edge of the Indiana Dunes National Lakeshore (INDU), are partially bounded (West Lagoon) by steel plant property that may impact the biota of the lagoons. If sediments of the West Lagoon are impacted in a similar way to those in the Grand Calumet River, then the contamination of these sediments may significantly affect aquatic biota and water birds that feed in the lagoons.

State resource biologists and park managers at the INDU are concerned that sediment contaminants may significantly impact aquatic organisms of the Grand Calumet Lagoons. Currently, the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and the Indiana Department of Environmental Management are developing plans to remediate

toxic sediments in the Grand Calumet River System. Therefore, information that quantifies the toxic potential of sediments in the Grand Calumet Lagoons could help in management decisions of remediation in these waters. The objective of this study was to assess the toxicity of sediments of the Grand Calumet Lagoons to aquatic organisms using standard aquatic toxicity testing.

IV. Methods

Study Site-

The Grand Calumet Lagoons are located at the western edge of the Indiana Dunes National Lakeshore, near Gary, Indiana. The western portion (West Lagoon) is surrounded by an industrial landfill and storage area that includes slag waste and coke piles (Figure 1). Additionally, the site surrounding the West Lagoon includes an unlined hazardous waste pit that received 20 tons/year of tar decanter wastes over a 20-year period. The eastern portion (Middle Lagoon) of the Grand Calumet Lagoons is influenced primarily by urban runoff (Figure 1). There is a restriction point between the Middle and West Lagoon that limits water flow between the two systems. Although the Middle Lagoon is not immediately surrounded by industrial sites, it may receive pollutants from groundwater and atmospheric sources. However, for the purposes of this study, we considered the Middle Lagoon to be an "upstream" reference site for determining impacts in the West Lagoon.

We chose seven sites in the Grand Calumet Lagoons (ML1, ML3; WL1-WL5) for collecting sediments for toxicity assays. The sites were selected to insure that both unimpacted (reference sites) and suspected impacted areas were included.

Sample Collection-

We collected sediments from 1994 to 1995 for contaminant analyses and toxicity assays (Table 1). Core samples were collected by forcing a site-dedicated 7 cm diameter PVC pipe into the top 20-30 cm of sediment. Three to four samples at each site were mixed in a plastic bucket, excess water was decanted, and sediments stored in air-tight, polyethylene jars. Sediment samples were kept on ice for transport and stored in the dark at 4°C until used. With the exception of tests with *Pimephales* larvae, sediment samples were used for toxicity assays within three weeks of collection. Assays with *Pimephales* larvae were completed with sediments that were stored for five weeks.

Contaminant Analyses-

One sediment sample from each site was analyzed for texture, composition, and 22 contaminants by contract with A & L Great Lakes Laboratories, Inc.[1], Fort Wayne, Indiana. Additionally, sediments from three sites (ML2, WL4, WL5) were analyzed for another 15 acid-extractable organic contaminants and 78 base-neutral organic contaminants, including polycyclic aromatic hydrocarbons (PAHs).

Toxicity Assays-

The toxicity of sediments was measured using modified American Society for Testing and Materials protocols for testing sediment toxicity (American Society for Testing and Materials 1993). Assays were performed using the cladoceran, *Ceriodaphnia dubia*; fathead minnow larva, *Pimephales promelas*; and the amphipod, *Hyalella azteca*.

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[1] Copies of analytical reports are available on request to P. Stewart or R. Gillespie. The mention of this company does not imply endorsement by the authors nor the federal government.

Pimephales larvae and *Hyalella* were purchased from Aquatic Research Organisms, Inc., Hampton, New Hampshire[1] . *Ceriodaphnia dubia* cultures were obtained from the U.S. Environmental Protection Agency, Cincinnati, Ohio. All organisms were maintained in the laboratory at Indiana University-Purdue University Fort Wayne using recommended U.S. Environmental Protection Agency protocols or those from the supplier (U.S. Environmental Protection Agency 1989; U.S. Environmental Protection Agency 1994).

Crooked Lake water (CL) was used for whole sediment assays and for washing sediments to create sediment elutriates. Crooked Lake is a natural, mesotrophic lake in Noble County, Indiana. Crooked Lake sediment was used as a reference for *Ceriodaphnia* assays. For sediment elutriate assays, we used Crooked Lake water as a reference treatment. Crooked Lake water was filtered (2 μm) and refrigerated prior to use in cultures and toxicity tests.

Pimephales larvae were maintained in aged, dechlorinated tap water. *Hyalella* were maintained in untreated Crooked Lake water, and *Ceriodaphnia* were cultured in sterilized Crooked Lake water. *Pimephales* and *Ceriodaphnia* were used to assay toxic effects in whole sediment and sediment elutriate. *Hyalella* were used in whole-sediment assays only. The measures used to estimate toxic effects included, survival in all species and growth in *Pimephales* and *Hyalella* (Table 1).

Bioassay Conditions-

The toxicity assays were performed either in a large environmental chamber or in an environmentally-controlled room (Table 1). Water quality measurements were recorded regularly to detect differences in physical and chemical variables among toxicity treatments.

Pimephales larvae were fed daily with live brine shrimp less than 24 hours old. *Ceriodaphnia* were fed daily with a

combination of *Selenastrum* algal cells and a solution of yeast-CEROPHYLL-trout chow (YCT; U.S. Environmental Protection Agency 1989). *Hyalella* were fed flake fish food twice during the 20-day and 30-day assays.

Pimephales larvae and *Hyalella* were preserved in 70% ethanol at the end of the assays. Weight and growth measurements of *Pimephales* larvae and *Hyalella* were made within two weeks of preservation.

Whole Sediment Bioassays-

Sediments were placed in a bucket, mixed and the appropriate weight (wet weight) was placed in the test chamber (Table 1). A volume of Crooked Lake (CL) water was added and sediments were allowed to settle overnight. Organisms were placed into the chambers the next morning and water lost to evaporation was replaced when necessary. Dead organisms were removed and physical and chemical measurements were recorded daily. For the 30-day *Hyalella* assay, *Hyalella* were removed from the initial sediment samples and transferred to new sediments at day 15. For all other assays, organisms were maintained in the initial sediments or elutriate.

Sediment Elutriate Assays-

Two hundred and fifty grams of sediment (wet weight) were combined with 1,000 ml of filtered (2 µm) Crooked Lake water and stirred for 2 hours. The elutriate was allowed to settle overnight in a dark cold room and the supernatant was filtered (2 µm). Filtered CL water was used as a reference for sediment elutriate assays. Evaporative water loss was replaced as necessary. Organisms were checked daily and dead animals and young *Ceriodaphnia* were removed.

Weight and Length Measurements-

Pimephales larvae were dried on small, pre-weighed aluminum pans at 60°C for 2-4 hours and mean dry weight (mg) was recorded. Mean weight per individual was calculated by dividing the total larvae weight by the number of larvae on the pan. Each larva was measured for total length to the nearest 0.01 mm and mean length calculated for each treatment.

Hyalella were dried at 60°C for 2-4 hrs on filter paper and weighed individually to the nearest μg. After weighing, *Hyalella* were placed between two glass slides and scanned with a computer scanner to create an image file. Total lengths were determined by measuring the "tip to tail" image of the *Hyalella* and normalizing it to a known standard using an image analysis program (Sigma Scan for Windows).

Statistical Analysis-

The computer program Statview for Macintosh was used for Statistical comparisons of end-points among assays. Assay results were analyzed with a one-way analysis of variance (ANOVA) when data were normally distributed or the non-parametric, Kruskal-Wallis and Mann-Whitney U-tests when data did not qualify for ANOVA. Proportional survival was arc-sin transformed and sites were compared with the non-parametric Kruskal-Wallis test or ANOVA (*Hyalella* 20-day test only). Mean larval weights of *Pimephales* were calculated for each replicate and sites were compared with a Kruskal-Wallis test. Mean weights for *Hyalella* and mean lengths for *Hyalella* and *Pimephales* larvae were analyzed by ANOVA. If the Kruskal-Wallis test showed a significant difference ($p < 0.05$), then a Mann-Whitney U-test was used to determine significance between sites. If the ANOVA indicated a significant difference ($p < 0.05$), then the Fisher's PLSD analysis

determined significant differences between sites. All differences were considered significant if $p < 0.05$ (Zar 1984; Conover 1971).

A measure of the relative concentration of contaminants from the field and relative effects endpoints among bioassays was made to incorporate several variables into a single graphical representation. The relative estimator of contaminants and effects was calculated using a relative proportion measure that expresses end-points from potentially-toxic sites (West Lagoon WL1-WL5) to those from reference sites (Middle Lagoon ML1, ML3). For lagoon assays, the references were the means of either ML1 and ML3 or ML1, ML3, and CL. The relative proportion was calculated by dividing the contaminant variable or assay end-point of the site by the mean of the reference sites. We used mean relative proportions to graphically compare the concentration of contaminants and the effects of bioassays at contaminated sites with those of the reference sites.

V. Results

Contaminants in Sediments-

The texture and composition of sediments from sites in the Middle Lagoon and from sites WL1, WL2, and WL3 were similar (Table 2). Sediments from WL4 had a greater silt, clay and organic content than those from sites in the Middle Lagoon and from sites WL1, WL2, and WL3. Sediments from WL5 had a greater clay content and a much greater organic content than those from sites in the Middle Lagoon and from sites WL1, WL2, and WL3.

The concentrations of metals and trace elements were similar in sediments from ML1 and ML2 (Table 2). Sediments from ML3 had greater concentrations of As and S than those from ML1 and ML2. The concentrations of Se, Ni and S were greater in sediments of WL1 and WL2 than in those from Middle

Lagoon sites. Sediments from WL3 had concentrations of contaminants that were similar to ML1-ML3, except for slight elevations of Mn. Sediments from WL4 and WL5 had greater concentrations of 13 contaminants than those from Middle Lagoon sites and other West Lagoon sites. With the exception of WL3, concentrations of contaminants increase from the upper Middle Lagoon (ML1) to the lower West Lagoon (WL4, WL5). There was a considerable increase in contaminants at sites WL4 and WL5.

With the exception of those reported in Table 3, concentrations of all acid-extractable and base-neutral compounds were below detection levels (0.7 – 3.3 mg/l) in sediments from sites ML2, WL4 and WL5. No PAHs were detected in sediments from ML2. Three polycyclic aromatic hydrocarbon (PAH) contaminants were detected in sediments from WL4 (Table 3). Sediments from WL5 had extremely high concentrations of PAH compounds. Eight PAH compounds in whole sediments from WL5 were found at concentrations as high as 1-95 g/kg.

Effects of Sediments and Sediment Elutriate-

Preliminary whole-sediment bioassays showed that sediments from WL5 were completely lethal to *Pimephales* larvae within 12 hours (Table 4). However, survival, mean weight, and mean length of *Pimephales* larvae did not differ significantly after 10 days of exposure to sediments from other sites (ML1-WL4) and the reference assays (CL). Because they were highly toxic to *Pimephales* larvae and posed an assumed hazard to personnel, we did not test other organisms with sediments from WL5.

Survival and weight of *Pimephales* larvae exposed to sediment elutriate did not differ significantly among sites (Table 4). Length of larvae exposed to sediment elutriates from site WL3 was significantly longer than those from ML1 and ML3. However, length did not differ significantly among other sites.

Ceriodaphnia were maintained in individual exposure cups. Therefore, there were no true replicates for statistical analyses of survival among sites. Survival of *Ceriodaphnia* was best in whole sediments from CL and ML3 (Table 5). *Ceriodaphnia* exposed to sediments from ML1 and WL1 had moderate mortality (45-55%), while those exposed to sediments from WL2 and WL3 had nearly complete mortality (85%). Interestingly, survival of *Ceriodaphnia* at WL4 was good (80%).

The survival of *Ceriodaphnia* in sediment elutriates from WL2, WL3, and WL4 was very low (Table 5). However, *Ceriodaphnia* in elutriate from ML1 had an unexpected 40% mortality. Survival of *Ceriodaphnia* in CL water was 80%, while those in elutriate from ML3 and WL1 (100%) had the highest survival.

There were no significant differences in percent survival of *Hyalella* exposed to whole sediments for 20-days (Table 6). The weight of *Hyalella* in whole sediment bioassays varied, but no clear relationship among sites resulted. However, the weight of *Hyalella* in 20-day assays was significantly less ($p < 0.05$) in sediments from WL1 and WL4 than in *Hyalella* exposed to sediments from ML1 and ML3. *Hyalella* exposed to sediments from sites ML3-WL4 were significantly shorter than those from ML1.

Survival of *Hyalella* was less at 30 days of exposure than at 20 days of exposures at 5 of 6 sites (Table 6). Although survival of *Hyalella* in sediments from ML1 and ML3 was 0.88 and 0.83, respectively, *Hyalella* survival above 0.80 is considered "acceptable" for reference treatments in sediment toxicity assays (Ingersoll, et al. 1995). Survival of *Hyalella* exposed to sediments from WL4 was significantly less than that of all other sites in 30-day assays. Survival of *Hyalella* did not vary significantly among assays with sediments from other sites. The weight of *Hyalella* exposed to sediments from WL1 was significantly less than that of all other sites except WL2. *Hyalella* exposed to sediments from

ML1 were the largest, but did not differ significantly from those exposed to sediments from ML3, WL3, and WL4. Mean length of *Hyalella* exposed to sediments from WL1 was significantly less than that of *Hyalella* exposed to sediments from all other sites, except WL4. *Hyalella* exposed to sediments from ML1 were significantly longer than those from all other sites.

Of three species tested with whole sediments, survival and growth in *Hyalella* most closely followed the concentrations of contaminants in whole sediments. Survival of *Hyalella* was low in sediments from WL4 in the 30-day toxicity assay. Additionally, growth (weight and length) of *Hyalella* was consistently lower in sediments from West Lagoon sites than those from Middle Lagoon sites. The survival at 30 days, and growth at 20 and 30 days of *Hyalella* exposed to sediments from WL1 was less than that in sediments from WL2 and WL3. The relative degree of contamination at WL1 is greater than that at WL2 and WL3 (Figure 2). Thus, the *Hyalella* toxicity assays may be sensitive to small differences in concentration of toxic contaminants.

VI. Discussion

Contaminants in Sediments-

The concentration of contaminants in sediments from the West Lagoon indicate that surrounding land use has had a negative impact on the West Lagoon of the Grand Calumet Lagoons. The concentration of metals and other contaminants in sediments from WL1-WL3 were as much as 2.5 times greater than those at ML1-ML3 (Figure 2). Concentrations of metals in sediments from WL4 and WL5 were 8 to 9 times greater than those of ML1-ML3. Additionally, sediments from WL4 may be contaminated with low levels of PAHs and sediments from WL5 are highly contaminated with many toxic PAH compounds. PAHs at WL5 comprise over 10% of sediment weight. Similar high

concentrations of PAHs at WL5 were found by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers 1997).

The extent of the greatest heavy metal contamination in sediments may be limited to the western half of the West Lagoon. Additionally, when compared to other water systems with contaminated sediments, the concentrations of heavy metals at WL4 and WL5 are either at the lower end of the range or below the lowest concentration of metals reported (Table 7). Therefore, the elevated concentrations of metals at WL4 and WL5 indicate mild heavy metal pollution compared to other contaminated sites.

Sediments from WL4 and WL5 in the West Lagoon are also contaminated with PAHs. The concentration of PAHs in sediments from WL4 are just above or at detection levels of analysis. Thus, sediments from this part of the West Lagoon may be only mildly contaminated with PAH compounds. Therefore, sediments at WL4 may be near the eastern most extent of PAH contamination in sediments of the West Lagoon.

When compared to other polluted rivers, sediments from WL5 are heavily contaminated with PAHs. Concentrations of PAHs in sediments from WL5 are an order of magnitude greater than those in sediments of the Black River, Ohio, analyzed in 1980 (Table 8). Contamination of sediments with PAHs in the Black River originated from coking facilities at a nearby steel production plant (Baumann and Harshbarger 1995). Concentrations of PAHs in sediments at WL5 are similar to those at a highly contaminated site in the Elizabeth River, Virginia, whose source was ultimately a creosote plant (Roberts, et al. 1989). With the exception of a few low-molecular weight PAHs (acenaphthene, acenaphtylene, naphthalene), the relative concentration of PAH compounds in sediments of WL5 are similar to those in the Elizabeth River site. When compared to other polluted sites, the extreme western portion of the West Lagoon is mildly contaminated with heavy metals, but is highly contaminated with PAHs.

Effects of Contaminated Sediments-

Reference Sites

Water and sediments from Crooked Lake, and sediments from the Middle Lagoon (ML1, ML3) were used as references to detect suspected toxicity in sediments from West Lagoon sites (WL1-WL5). Survival and growth of *Pimephales* larvae and *Hyalella* in reference assays were consistently better or similar to that in assays with sediments from West Lagoon sites (Figures 3 and 5). Additionally, survival and growth of *Pimephales* and *Hyalella* did not vary greatly among reference assays. However, survival of *Ceriodaphnia* in whole sediments and elutriate from ML1 was lower than that in assays of CL and ML3 (Figure 4). Sediments for whole-sediment and elutriate assays were collected from ML1 on different sampling dates. However, both assays resulted in greater mortality of *Ceriodaphnia* at ML1 than in sediments and elutriates from CL and ML3. Since the concentrations of contaminants in sediments from ML1 were below those of other sites, it is possible that characteristics other than toxicants in the sediments are responsible for low survival of *Ceriodaphnia*.

West Lagoon Sites WL1-WL3

We expected sediments from WL1-WL3 of the West Lagoon to be slightly toxic to aquatic organisms. However, exposure of *Pimephales* larvae to sediments and elutriate from WL1-WL3 had no effect on survival or growth (Figure 3). The poor survival of *Ceriodaphnia* in whole sediments and elutriate from WL2 and WL3 (Figure 4) should be interpreted with caution, because survival was not analyzed statistically.

Survival of *Hyalella* in sediments from WL1-WL3 was not significantly different from that in sediments from ML1 and ML3 at 20 days of exposure (Figure 5). After 30 days of

exposure, survival of *Hyalella* in whole sediments from WL1 (65%) was less than that at ML1 (88%; $p = 0.06$) and at ML3 (83%; $p = 0.08$). When combined with the apparent sublethal effects of exposure (weight and length) to sediments from WL1 ($p < 0.05$), the assays showed slight toxic effects at WL1 to *Hyalella*. The mean weight and length of *Hyalella* exposed to sediments from WL1 for both 20-d and 30-d assays were the lowest of all sites and significantly less than those in sediments from ML1 and ML3. Because these two assays (20-d, 30-d) used different sediment samples, our results suggested that sediments from WL1 were slightly toxic to *Hyalella*.

The relative concentration of contaminants in sediments from WL1 were greater than that in WL2 and WL3 (Figure 2). Therefore, the apparent effects of sediments from WL1 on growth in *Hyalella* may have resulted from one or more of the contaminants analyzed. Day, et al. (1995) found that exposure of *Hyalella* to sediments spiked with concentrations of metals at 1-2 mg/kg for 28 days resulted in good survival (96%), but less growth (75%) than reference *Hyalella*. Because the concentrations of metals in the sediments of WL1 are in this range, it is possible that metals caused sublethal effects in *Hyalella* in our assays.

West Lagoon Site WL4

Because of the elevated metals and possible trace amounts of PAHs, we expected sediments of WL4 to be toxic to aquatic organisms. However, whole sediments from WL4 had no effect on survival and growth on *Pimephales* larvae, nor on survival of *Ceriodaphnia* (Figures 3 & 4). Although sediment elutriate had no effect on survival and growth in *Pimephales* larvae, survival of *Ceriodaphnia* was very poor in elutriate from WL4. Because survival of *Ceriodaphnia* was good in whole sediment from WL4, but poor in elutriate, it is possible that water-soluble contaminants, not available to *Ceriodaphnia* in whole sediments, were released by washing.

Our finding that elutriates were more toxic than whole sediment at WL4 for *Ceriodaphnia* differs from that of other studies. In bioaccumulation experiments, Harkey, et al. (1994) found that sediment elutriates underexposed *Hyalella*, chironomids and annelids to PAHs when compared to whole sediments. Additionally, elutriates from contaminated sediments of Indiana Harbor and the Scioto River were considerably less toxic than whole sediments to *C dubia* and *Hyalella* (Harkey, et al. 1994; Burton, et al. 1989). In addition to diluting contaminants, the washing of whole sediments to create elutriate may change the chemistry and bioavailability of toxic compounds (Sasson-Brickson and Burton 1991; Burton, et al. 1989). These alterations of contaminants could result in less toxicity to bioassay organisms.

The apparently greater toxicity of elutriate than whole sediment at WL4 for *Ceriodaphnia* could be a result of the type of contaminants, composition of sediment, or the water used for washing. Since the sediments used for whole sediment assays and elutriate toxicity assays came from different samples in our study, the interpretation of differences in toxicity between these two media for *Ceriodaphnia* should be considered preliminary.

Survival of *Hyalella* in whole sediments from WL4 was good at 20 days of exposure, but significantly less than all other sites after 30 days (Figure 5). The mean weight of surviving *Hyalella* in whole sediments from WL4 was significantly less than that in sediments from ML1 and ML3 at 20 days of exposure, but did not differ from reference sites at 30 days. Since survival in sediments from WL4 was low at 30 days of exposure, it is possible that only large *Hyalella* survived at 30 days or that the release of competition for food allowed for increased growth of survivors relative to growth of survivors in the 20-day assay. The mean length of *Hyalella* exposed to sediments from WL4 was significantly less than that of *Hyalella* in ML1 sediments, but did not differ

from mean length of *Hyalella* from ML3 and WL1-WL3 at 20 and 30 days of exposure.

Assays indicated that sediments from WL4 caused adverse effects on *Ceriodaphnia* and *Hyalella*. *Ceriodaphnia dubia* had poor survival in elutriate and *Hyalella* had poor survival (30-d) in whole sediments from WL4. However, *Pimephales* larvae were unaffected by sediments and elutriate from WL4. It is possible that minnow larvae were not exposed to contaminants in whole sediments or that they have physiological and biochemical mechanisms that confer greater resistance to toxicity of contaminants.

West Lagoon Site WL5

We predicted that the elevated heavy metals and extremely high concentrations of PAHs in sediments of WL5 would be acutely toxic to aquatic organisms. Because *Pimephales* larvae exposed to whole sediments from WL5 died within hours, these sediments should be considered very toxic to aquatic organisms. Minnow larvae were not negatively affected by sediments from any other site in the West Lagoon. However, sediments from sites WL1-WL4 did produce some negative effects in *Ceriodaphnia* and *Hyalella*. Since *Pimephales* were more resistant to toxic effects of sediments than *Ceriodaphnia* and *Hyalella* at other sites, we believe that sediments from WL5 would have been acutely toxic to all aquatic organisms.

Toxicity of Sediments in the West Lagoon-

The bioassays with sediments from WL1-WL4 did not produce the level of toxicity in aquatic organisms we expected based upon the relative degree of metal contamination in the West Lagoon (Figure 2). However, when compared to the toxicity and biological effects of metals to aquatic organisms published in other studies, the

concentrations of metals in sediments at sites WL1-WL4 may only cause minor (low-level) effects. Most of the metal concentrations in sediments from WL1-WL4 are below that necessary to cause low-level effects (Long and Morgan 1990) in aquatic organisms (see ER-L in Table 9). Additionally, when compared to the no-effect concentrations (NEC) for growth in *Hyalella* exposed to metal-contaminated sediments (Ingersoll, et al. 1993), nearly all of the concentrations of metals in sediments from WL1-WL4 are well below that necessary to cause significant effects (Table 10). Only concentrations of Cr, Pb, and Zn in sediments from WL4 approach those necessary to cause low-level effects in *Hyalella* (Tables 9 & 10).

We expected sediments from WL4 to be toxic to aquatic organisms because they were contaminated with metals and had slightly elevated PAH compounds. Although the concentration of metals in sediments at WL4 may not cause significant toxic effects, the presence of PAHs could have caused toxicity. However, the concentration of PAHs in sediments from WL4 may be below that necessary to cause significant toxicity to aquatic organisms. Concentrations of three PAH compounds in sediments at WL4 were at or slightly above detection levels. When compared to concentrations that cause biological effects in aquatic organisms, it appears that PAH concentrations in sediments from WL4 would not cause significant biological effects (Table 11). Therefore, although we expected significant toxicity in sediments from WL4, data show only slight to moderate toxic effects in aquatic organisms.

An alternative explanation for a lack of significant toxicity in sediments and elutriate from WL1-WL4 could be the storage time for sediments. Whole sediments were stored at 4°C from 2 days to 5 weeks prior to the beginning of toxicity assays. The U.S. Environmental Protection Agency and U.S. Army Corps of Engineers recommend that sediments be used within two weeks of their collection (Moore, et al. 1995). Thus, physical and chemical changes in sediments stored

between two to five weeks could have resulted in less contaminant concentrations or bioavailability than in-situ sediments. However, the U.S. Environmental Protection Agency and U.S. Army Corps of Engineers suggest a limit to storage time for sediments at 4°C of up to six weeks. Additionally, storage of sediments with heavy metals for 18 days (Ingersoll, et al. 1993) and for sediments with moderate metal and PAH contamination for two years (Moore, et al. 1995) had no effect on toxicity to aquatic organisms. Therefore, it is unlikely that storage time of sediments significantly affected the results of toxicity assays in our study.

The media of exposure may affect the toxicity of sediment-bound contaminants. Typically, interstitial water (pore water) is more toxic than whole sediments, while whole sediments are more toxic than sediment elutriate (Ingersoll, et al. 1993; Winger and Lasier 1995; Harkey, et al. 1994; Burton, et al. 1989). Pore water is more toxic than whole sediments (10-day LC50 for metals range from 2-800 μg/L) because the contaminants in water are more readily available to aquatic organisms than those bound to sediment particles (Ingersoll, et al. 1993). Therefore, assays with pore water from sites WL1-WL4 may have resulted in greater toxicity than that with whole sediments. However, the concentration of metals in pore water is as little as 10^{-4} that of concentrations in whole sediments (Ingersoll, et al. 1993). Since concentrations of metals in whole sediments from WL1-WL4 were only slightly elevated, it is unlikely that exposure to only pore water from these sediments would have caused significant toxic effects.

The sediments from WL5 were extremely toxic to *Pimephales* larvae. All minnow larvae died within hours of exposure to whole sediments from WL5. Although sediments from WL5 had concentrations of metals that could contribute to toxicity (Tables 9 & 10), the extremely high

concentrations of PAHs in sediments from this site were acutely toxic. The concentrations of PAHs in sediments from WL5 were more than an order of magnitude greater than those necessary to cause major biological effects in aquatic organisms (Table 11). Additionally, despite the tight binding of PAHs to organic particles in sediments (McGroddy, et al. 1996), the concentrations of these compounds in whole sediments from WL5 should produce concentrations of PAHs in interstitial water that would exceed the 10-day LC50 for *Hyalella* (Table 11). It is also possible that synergistic effects among PAHs and among metals and PAHs could contribute to acute toxicity in sediments from WL5.

Despite the difference in normalization of concentrations (whole sediment weight vs. organic content), the levels of PAH compounds in whole sediments from WL5 exceeded the mean sediment quality criteria to protect freshwater life (100-1,000 mg/kg organic carbon) proposed by the U.S. Environmental Protection Agency (Pastorok, et al. 1994). By all measures, sediments from WL5 should be acutely toxic to all aquatic organisms. In a study with contaminated sediments from the Elizabeth River that had PAH compounds in the same range as those in WL5 (see Table 8), the authors reported an LC50 of 58% for assays with juvenile spot exposed for 1-5 days (Roberts, et al. 1989). Sediments from the Elizabeth River with PAHs at about one-half the concentration of those at WL5 killed 50% of juvenile fish within 1-5 days. Evidence from the literature and data from our study suggest that the sediments of WL5 are acutely toxic to all aquatic organisms.

VII. Conclusions

The results of this study should be used to focus attention and efforts on priority problems of impacts in the West Lagoons. Sediments at WL1-WL3 may produce slight negative effects to aquatic organisms. The negative effects

from sediments of WL1 to *Hyalella* were somewhat surprising, yet the metal contamination of sediments was greater at WL1 than at WL2 and WL3. Although the concentrations of metals in sediments of WL1 are only slightly elevated, the sources of these contaminants should be identified. The sediments of WL1 are in the east portion of the West Lagoon whose shoreline and surrounding land is within the Indiana Dunes National Lakeshore. Thus, identification of sources of contamination at WL1 may identify sources of impact (e.g., atmospheric or slag runoff) to other areas of the park.

Sediments at WL4 may produce negative effects on aquatic organisms. Although the level of contamination of metals and PAHs suggested only slight potential for toxic effects, we detected negative effects from sediments of WL4 to *Ceriodaphnia* and *Hyalella*. Because PAHs were found near detection levels, the sediments of WL4 may represent the furthest eastern extent of PAH contamination in the West Lagoon.

Sediments from WL5 were slightly contaminated with metals, but had extremely high concentrations of PAHs. These sediments are acutely lethal to aquatic organisms and should receive immediate attention. Sediments with concentrations of PAHs that were considerably less than those of WL5 (see Table 8) have been correlated with incidences of tumors in natural populations of fishes (Baumann 1992; Baumann, et al. 1991; Baumann and Harshbarger 1995). Therefore, it is very likely that the sediments of WL5 have contributed to significant negative biological effects in the West Lagoon.

Because volatile, lower molecular weight PAH compounds (e.g. naphthalene) were relatively higher in concentration than heavier ones, the source of PAH contamination in the West Lagoon may be ongoing. The extent of contamination and risks of toxicity of PAHs in sediments of the West Lagoon needs to be considered in any plans for remediation. More importantly, the source of PAHs and metals needs to be identified and terminated for remediation to be effective.

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Figure 1. Collection sites for sediments in the Grand Calumet Lagoons Middle Lagoon (ML1-ML3), West Lagoon (WL1-WL5).

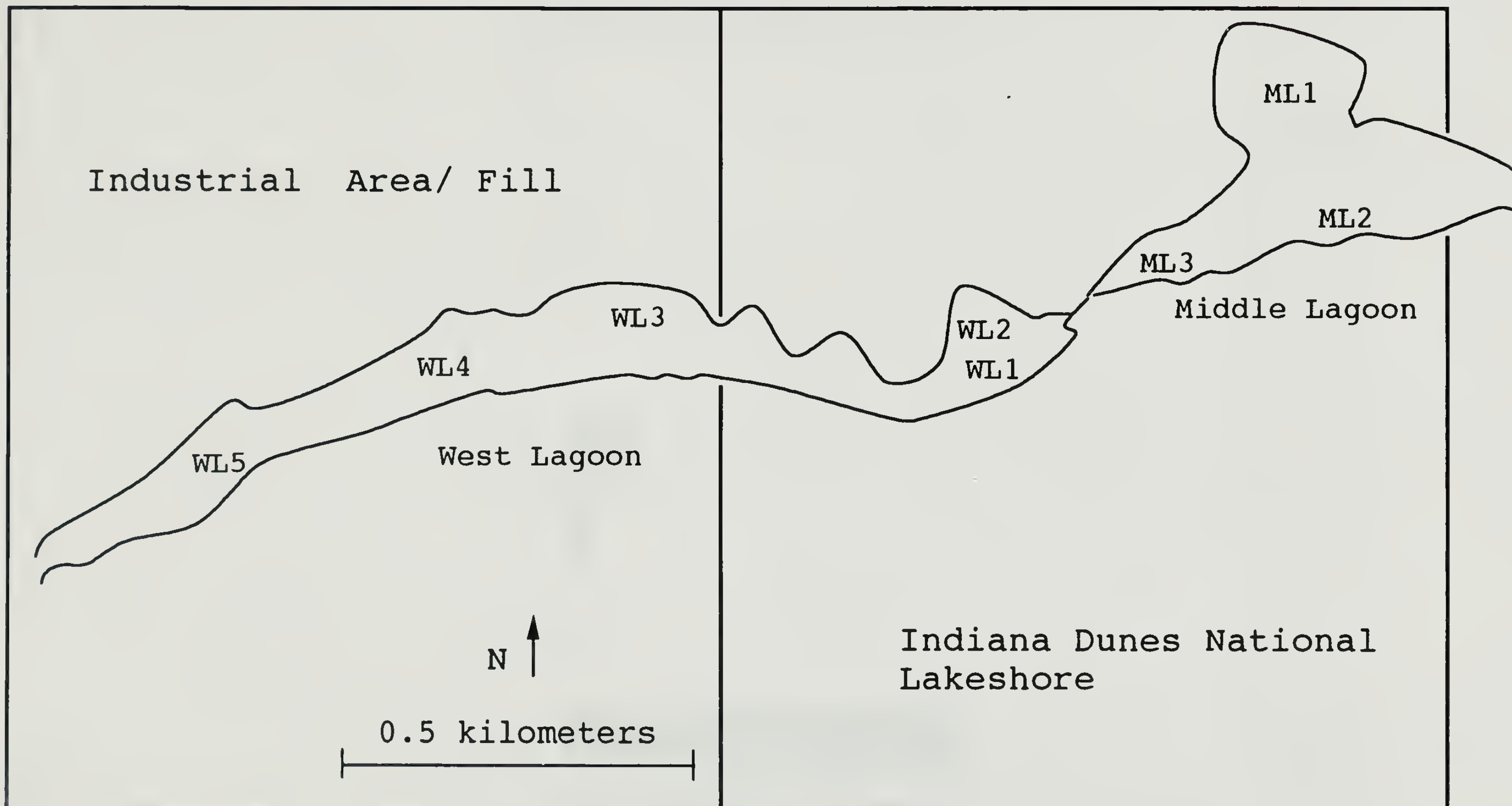

Figure 2. Mean relative proportion of 18 contaminants (excluding PAHs) in sediments of the Middle Lagoon (ML1-ML3) and West Lagoon (WL1-WL5). A value of 1.0 is the mean of reference sites ML1, ML2 and ML3.

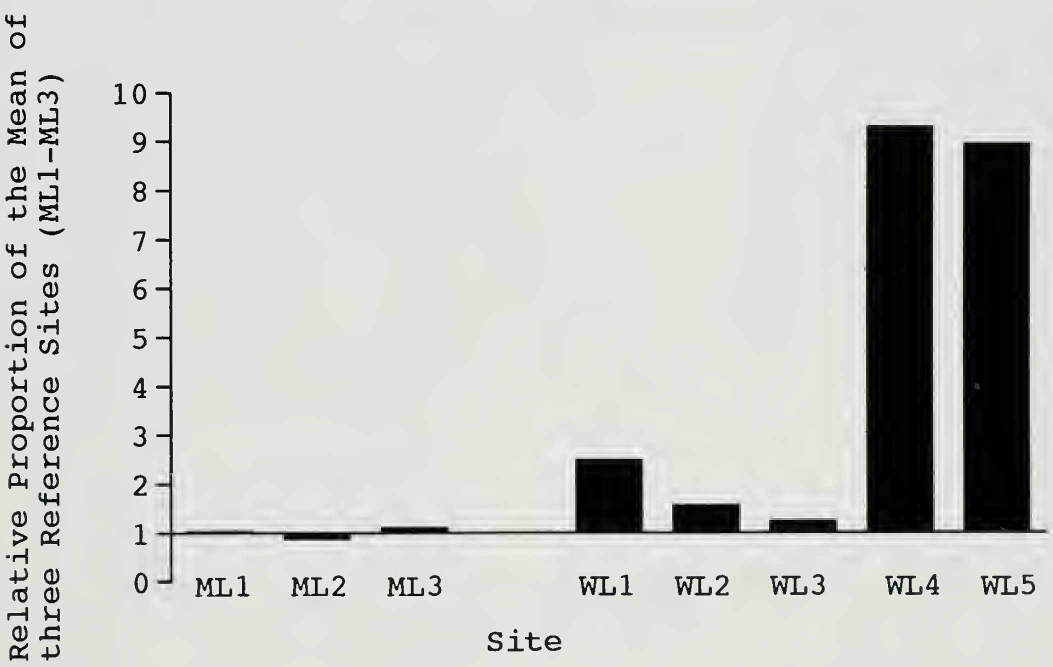

Figure 3. Relative proportions for effects on *Pimephales* of whole sediments and sediment elutriate from the Middle Lagoon (ML1-ML3) and West Lagoon (WL1-WL5). A value of 1.0 represents the mean of three reference sites (CL, ML1, ML3). Crooked Lake water (CL) was used as a reference for whole sediment and sediment elutriate assays. ** Whole sediments from WL5 caused 100% mortality within 12 hours.

Figure 4. Relative proportions for survival of *Ceriodaphnia* in whole sediments and sediment elutriate from the Middle Lagoon (ML1-ML3) and West Lagoon (WL1-WL4). A value of 1.0 represents the mean of three reference sites (CL, ML1, ML3). Crooked Lake sediments and water (CL) were used as references.

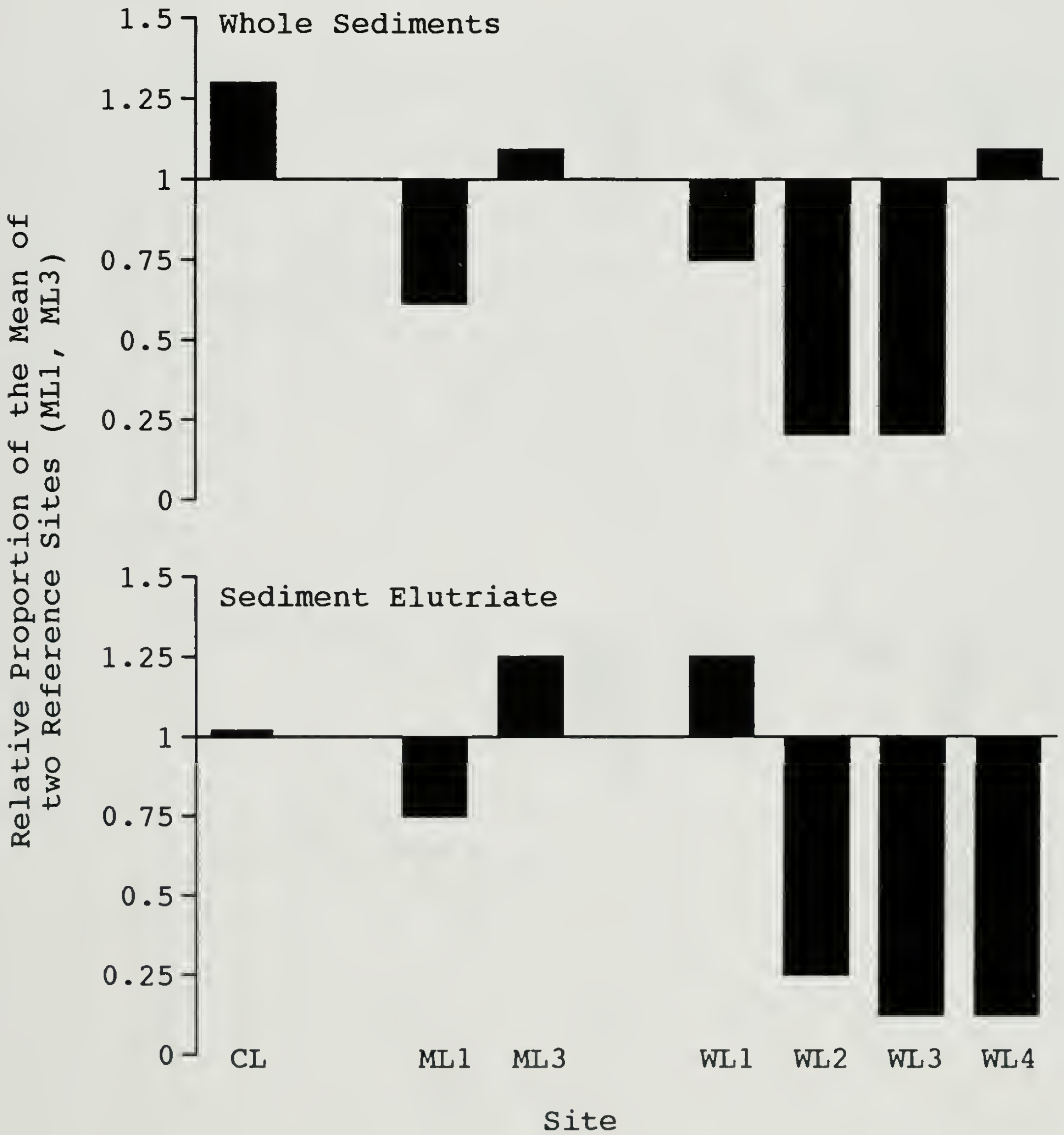

Figure 5. Relative proportions for effects on *Hyalella* of whole sediments from the Middle Lagoon (ML1-ML3) and West Lagoon (WL1-WL4). A value of 1.0 represents the mean of two reference sites (ML1, ML3).

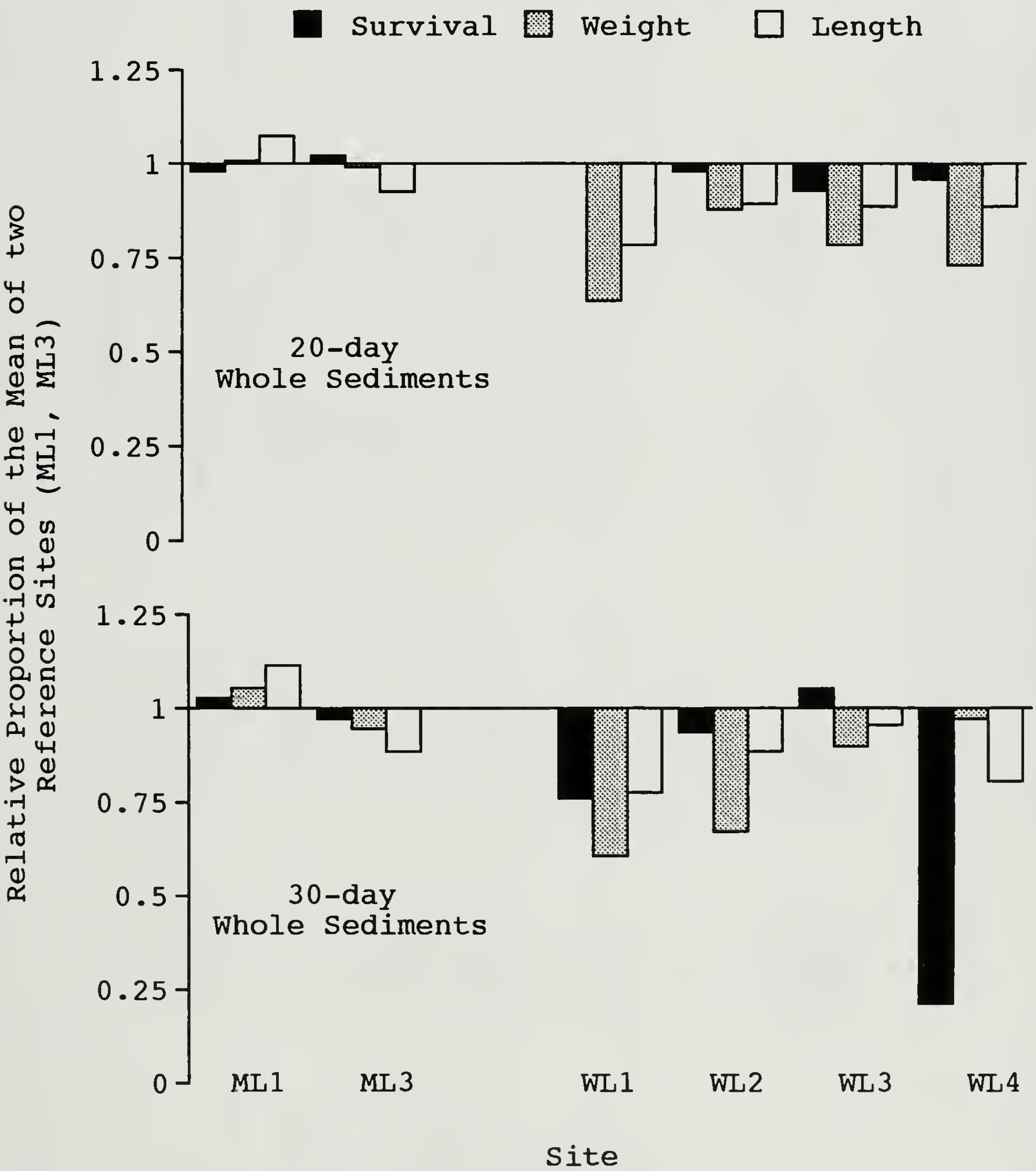

Table 1. Test conditions of whole-sediment and sediment-elutriate bioassays with sediments from the Middle and West Lagoons. All tests were static and run at 20-25°C with a photoperiod of 16 hr:8 hr, light:dark cycle. Survival= percent survival.

Test Condition[1]	*Pimephales*		*Ceriodaphnia*		*Hyalella*	
	Whole Sediment	Sediment Elutriate	Whole Sediment	Sediment Elutriate	Whole Sediment 20-day	Whole Sediment 30-day
Storage Time	5 weeks	5 weeks	2 days	3 weeks	4 weeks	2 days
Sediment[2] Volume	60 g 250 ml	250 ml	5 g 20 ml	20 ml	5 g 20 ml	60 g 250 ml
Age of Test Organism	<24 hr	<24 hr	<24 hr	<24 hr	7-14 d	7-14 d
Organisms per Chamber	10	10	1	1	5	10
Replicates per Site	4	4	20	10	10	4
Duration	10 d	12 d	7 d	8 d	20 d	30 d
Endpoints	Survival Length Weight	Survival Length Weight	Survival	Survival	Survival Length Weight	Survival Length Weight

[1] Dilution water was sterilized, filtered Crooked Lake water with an alkalinity of 100-120 mg/L, hardness of 140-200 mg/L, and conductivity of 220-260 µmhos/cm.

[2] For sediments from WL4 and WL5, 10g/250ml were used instead of 60g/250ml and 1g/20ml was used instead of 5g/20ml because their composition was highly organic and light in weight.

Table 2. Selected physical and chemical properties and contaminant concentrations in sediments of the Middle (ML1-ML3) and West Lagoon (WL1-WL5). Analyses were performed on one sample for each site. Except for texture, percent organic matter, and pH, all values are mg/kg. Detection levels for mercury, selenium and arsenic were 0.02 mg/kg. Detection levels for other elements were 1.0 mg/kg. BDL= below detection level. Samples were collected on 7-20-94 and analyzed on 7-21-94.

Variable	ML1	ML2	ML3	WL1	WL2	WL3	WL4	WL5
Texture								
% Sand	97	97	95	93	95	97	75	89
% Silt	2	2	2	4	4	2	16	5
% Clay	1	1	3	3	1	1	9	6
% Organic	0.2	0.1	0.4	0.8	0.2	0.1	5.1	34.1
pH	7.9	7.9	8.0	8.1	8.1	8.3	8.0	8.4
Mercury	BDL	BDL	BDL	BDL	BDL	BDL	0.05	0.12
Selenium	0.04	0.06	0.04	0.37	0.11	0.03	0.69	1.10
Nickel	BDL	BDL	BDL	1.10	0.90	1.00	3.10	2.90
Arsenic	0.59	0.75	2.90	3.70	1.60	0.61	8.20	8.60
Copper	BDL	BDL	BDL	2	1	1	11	10
Chromium	1	1	1	2	1	2	15	19
Barium	3	3	3	4	3	3	20	19
Lead	3	2	3	6	5	3	36	30
Sodium	24	18	17	22	34	21	96	61
Potassium	41	34	35	46	36	45	140	80
Phosphorous	47	40	41	44	47	48	99	119
Zinc	9	6	9	15	15	10	114	123
Manganese	29	18	22	28	36	60	488	368
Aluminum	363	369	404	483	284	404	722	936
Magnesium	1,440	938	1,050	979	565	1,560	536	806
Sulfur	195	110	325	2,740	1,710	351	6,560	5,010
Calcium	3,220	2,910	3,480	2,930	1,900	4,050	14,200	13,300
Iron	1,670	1,770	2,170	4,610	2,050	2,280	20,700	11,100

Table 3. Concentrations of 17 organic contaminants (mg/kg) in a sediment sample from one site in the Middle Lagoon (ML2) and from two sites in the West Lagoon (WL4, WL5). Detection levels for all contaminants were 0.70 mg/kg. BDL= Below detection limit.

Contaminant	ML2[a]	WL4[a]	WL5[b]
Naphthalene	BDL	BDL	95,455
Acenaphthene	BDL	BDL	5,666
2-Methylnaphthalene	BDL	BDL	4,800
Dibenzofuran	BDL	BDL	4,184
Phenanthrene	BDL	BDL	3,286
Flourene	BDL	BDL	2,470
Flouranthene	BDL	0.70[c]	2,122
Pyrene	BDL	BDL	1,644
Anthracene	BDL	BDL	792
Benzo(a)anthracene	BDL	BDL	523
Chrysene	BDL	BDL	453
Benzo(a)pyrene	BDL	BDL	444
Benzo(b)flouranthene	BDL	0.80[c]	440
Acenaphthylene	BDL	BDL	425
Benzo(g,h,i)perylene	BDL	BDL	300
Ideno(1,2,3,-cd)pyrene	BDL	BDL	221
Benzo(k)flouranthene	BDL	1.00[c]	206

[a] Sediment from ML2 and WL4 were collected on 7-20-94 and analyzed on 7-21-94.

[b] Sediment from WL5 was collected on 11-7-94 and analyzed on 11-21-94.

[c] At or near detection level.

Table 4. Survival and growth (mean weight and length per individual) of *Pimephales* larvae (<24 hrs old) exposed to whole sediments (10-d), and sediment elutriate (12-d) from the Middle Lagoon (ML1, ML3) and West Lagoon (WL1-WL5). Crooked Lake water (CL) was used as a reference treatment for whole sediment and sediment elutriate assays. ND= no data

	Whole Sediments			Sediment Elutriate		
Site	Survival[1]	Weight[2]	Length[3]	Survival[1]	Weight[2]	Length[4]
CL	0.98	0.287	7.97	0.98	0.287	7.97
ML1	0.98	0.273	8.16	0.95	0.268	7.79[4]
ML3	0.98	0.280	7.99	0.98	0.303	7.79[4]
WL1	0.98	0.314	8.12	1.00	0.285	7.83
WL2	0.97	0.276	7.99	0.95	0.303	7.91
WL3	0.98	0.295	8.06	1.00	0.312	8.09[4]
WL4	0.93	0.285	8.00	0.98	0.292	7.87
WL5	0.00[5]	- - -	- - -	ND	ND	ND

[1] Proportion of 40 individuals surviving (10 larvae in 4 replicates; proportions of each replicate were Arc-sin transformed (N= 4); no significant differences among sites were found using a Kruskal-Wallis test ($p > 0.05$)

[2] Mean dry weight (mg) per individual of surviving larvae pooled within each of 4 replicates (N= 4); no significant differences among sites were found using a Kruskal-Wallis test ($p > 0.05$)

[3] Mean length (mm) per individual among surviving larvae; no significant differences among sites were found using ANOVA ($p > 0.05$)

[4] Mean length (mm) per individual among surviving larvae; mean length differed significantly between sites ML1 and WL3 and between sites ML3 and WL3 using ANOVA ($p < 0.05$)

[5] Preliminary assays completed separately from those reported here. All larvae died within 12 hours

Table 5. Survival of *Ceriodaphnia* exposed to sediments and sediment elutriate from Middle Lagoon (ML1, ML3) and West Lagoon (WL1-WL4). Sediments and surface water from Crooked Lake (CL) were used as references for whole sediment and elutriate assays.

	Adult Survival	
Site	Whole Sediments[1]	Sediment Elutriate[2]
CL	0.95	0.80
ML1	0.45	0.60
ML3	0.80	1.00
WL1	0.55	1.00
WL2	0.15	0.20
WL3	0.15	0.10
WL4	0.80	0.10

[1] Proportion of 20 individuals surviving (1 adult per replicate); 7-d exposure; no statistical analyses performed

[2] Proportion of 10 individuals surviving; 8-d exposure; no statistical analyses performed

Table 6. Survival and growth of *Hyalella* exposed to whole sediments from the Middle Lagoon (ML1, ML3) and West Lagoon (WL1-WL4) from two assays at 20 and 30 days of exposure. Sites with different letters are significantly different ($p < 0.05$).

	Adult Survival		Weight/Amphipod[3]		Length/Amphipod[4]	
Site	20d[1]	30d[2]	20d	30d	20d	30d
ML1	0.94 (a)	0.88 (a)	170 (a)	243 (a)	3.91 (a)	5.30 (a)
ML3	0.98 (a)	0.83 (a)	167 (ab)	218 (a)	3.37 (b)	4.21 (b)
WL1	0.96 (a)	0.65 (a)	107 (d)	140 (c)	2.85 (c)	3.69 (c)
WL2	0.94 (a)	0.80 (a)	148 (ac)	155 (bc)	3.25 (b)	4.21 (b)
WL3	0.89 (a)	0.90 (a)	132 (bcd)	207 (a)	3.23 (bc)	4.54 (b)
WL4	0.92 (a)	0.18 (b)	123 (cd)	224 (ab)	3.23 (bc)	3.83 (bc)

[1] Proportion of 50 individuals surviving (5 individuals in each of 10 replicates); proportions for each replicate were Arc-sin transformed; ANOVA (N= 10)

[2] Proportion of 40 individuals surviving (10 individuals in each of 4 replicates); proportions for each replicate were Arc-sin transformed; Mann-Whitney Test (N= 4)

[3] Mean weight (µg) per individual for surviving amphipods; N= 40-48 per site for 20-day assay, N= 7-35 per site for 30-day assay; ANOVA

[4] Mean length (mm) per individual for surviving amphipods; N= 37-44 per site for 20-day assay, N= 7-35 per site for 30-day assay; ANOVA

Table 7. Concentrations of metals in whole sediments from five contaminated sites and from WL4 and WL5 in the West Lagoon of the Grand Calumet Lagoons. All concentrations are mg/kg. ND= no data; BDL= below detection level.

Site	As	Cd	Cr	Cu	Ni	Pb	Zn
Hamilton Harbor[1]	15	7	162	126	68	233	2,292
Great Lakes Rivers[2]	4-175	<3-16	34-111	ND	22-70	ND	ND
Savannah River[3]	ND	2-7	10-75	5-130	5-30	25-180	25-400
Milltown Reservoir[4]	26-56	2-13	32-41	266-878	13-24	63-99	625-4,200
Clear Fork River[5]	11-404	26-56	29-45	128-7,820	9-16	38-679	365-10,090
Grand Calumet Lagoons (WL4)	8	BDL	15	11	3	36	114
Grand Calumet Lagoons (WL5)	8	BDL	19	10	3	30	123

[1] Single sample from one contaminated site (Day, et al. 1995).
[2] Range of five tributaries of the Great Lakes (Baumann, et al. 1991).
[3] Range of 26 stations; reference stations not included (Winger and Lasier 1995).
[4] Range of 6 sites; reference site not included (Ingersoll, et al. 1993).
[5] Range of 5 sites; reference site not included (Ingersoll, et al. 1993).

Table 8. Concentrations of PAHs in sediments (mg/kg) from two contaminated rivers and in sediments from WL4 and WL5 of the West Lagoon. ND= no data; BDL= below detection level.

	Black River[1]			West Lagoon	
PAH	1980	1987[2]	Elizabeth River[3]	WL4	WL5
Benzoflouranthenes	75	0.58	234	1.80[4]	646[4]
Benzo(a)pyrene	43	0.24	98	BDL	444
Chrysene	51	ND	317	BDL	453
Pyrene	140	0.93	1,350	BDL	1,644
Flouranthene	220	0.79	2,370	0.70	2,122
Anthracene	ND	ND	264	BDL	792
Phenanthrene	390	0.73	4,220	BDL	3,286
Flourene	ND	ND	1,250	BDL	2,470
Acenaphthylene	40	0.08	ND	BDL	425
Acenaphthene	36	0.14	ND	BDL	5,666
Naphthalene	ND	ND	95	BDL	95,455

[1] Baumann and Harshbarger (1995)

[2] PAH concentrations four years after termination of the source

[3] Roberts, et al. (1989)

[4] Σ benzo[k] + benzo[b] flouranthenes

Table 9. Concentration of effects range-low (ER-L), effects range-median (ER-M), and proportions of effects range-low for concentrations of metals in whole sediments from the West Lagoon. Proportion= Conc X_{lagoon}/Conc X_{ER-L}. ER-L and ER-M values are mg/kg. BDL= below detection level.

	Concentrations					
Effects	Cr	Ni	Pb	As	Zn	Cu
ER-L[1]	80	30	35	33	120	70
ER-M[2]	145	50	110	85	270	390
Site	Proportions					
ML1	0.01	BDL	0.09	0.03	0.07	BDL
ML3	0.01	BDL	0.09	0.09	0.07	BDL
WL1	0.02	0.03	0.17	0.12	0.12	0.03
WL2	0.01	0.03	0.14	0.06	0.12	0.01
WL3	0.02	0.03	0.09	0.03	0.08	0.01
WL4	0.19	0.04	1.03	0.24	0.95	0.16
WL5	0.24	0.04	0.86	0.27	1.02	0.14

[1] Concentration of chemical in sediment below which effects are rarely or never observed among species (Long and Morgan 1990)

[2] Concentration of chemical in sediment above which effects are frequently or always observed among most species (Long and Morgan 1990)

Table 10. Proportions of No-Effect Concentrations (NEC) for growth in *Hyalella* exposed to metals in whole sediments. Proportion= Conc X_{lagoon}/Conc X_{NEC}

Metal	NEC Whole Sediments[1] (mg/kg)	Proportion of the No-Effect Concentration for Whole Sediments from Sites in the West Lagoon						
		ML1	ML3	WL1	WL2	WL3	WL4	WL5
Cr	4	0.22	0.22	0.45	0.22	0.45	3.37	4.27
Ni	5	0.00	0.00	0.21	0.17	0.19	0.59	0.55
Pb	62	0.05	0.05	0.10	0.08	0.05	0.58	0.48
As	24	0.02	0.12	0.15	0.07	0.02	0.34	0.36
Zn	1,064	0.01	0.01	0.01	0.01	0.01	0.11	0.12
Cu	325	0.00	0.00	0.01	0.00	0.00	0.03	0.03
Total NEC Proportion		0.30	0.40	0.93	0.55	0.72	5.03	5.81

[1] No-Effect Concentration for growth in *Hyalella* exposed to contaminated whole sediments from two aquatic systems polluted with heavy metals (Ingersoll, et al. 1993)

Table 11. Comparisons of PAHs in whole sediments of the West Lagoon with concentrations of PAHs that cause significant effects. BDL= below detection level (0.70 mg/kg). ND= no data

PAH	10-d LC50[1] (mg/L)	ER-L[2] (mg/kg)	ER-M[2] (mg/kg)	MBEC[3] (mg/kg)	Grand Calumet Lagoon (mg/kg)	
					WL4	WL5
Benzo(k)flouranthene	0.00017	ND	ND	ND	1.0	206
Benzo(b)flouranthene	0.00038	ND	ND	ND	0.8	440
Benzo(a)pyrene	0.0019	0.40	2.50	2-20	BDL	444
Chrysene	0.0066	0.40	2.80	3-30	BDL	453
Pyrene	0.014	0.35	2.20	5-50	BDL	1,644
Flouranthene	0.029	0.60	3.60	7-35	0.7	2,122
Anthracene	0.180	0.08	0.96	1-15	BDL	792
Phenanthrene	0.240	0.22	1.40	5-100	BDL	3,286
Flourene	0.270	0.03	0.64	2-15	BDL	2,470
Acenaphthylene	0.490	ND	ND	8-20	BDL	425
Acenaphthene	0.970	0.15	0.65	2-7	BDL	5,666
Naphthalene	3.500	0.34	2.10	ND	BDL	95,455

[1] 10-d LC_{50} of interstitial water to marine and estuarine amphipods (Swartz, et al. 1995)
[2] Effects Range-Low and Effects Range-Median (Long and Morgan 1991)
[3] Concentrations in whole sediments considered to cause major biological effects (Clark and Jarvis 1990)